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AUTHOR	Resnick, Lauren B.
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ABSTRACT

This paper presents a model of an interactive mode for instructional research and development that might yield both curriculum products and scientific knowledge concerning learning and instruction. Curriculum development is discussed as an applied science and as an art, using specific research and development efforts conducted at the Learning Research and Development Center to highlight the present and potential character of the interactive model. Consideration is given to the roles of task analysis, diagnosis of learner characteristics, design of curricula and learning environments, and assessment and evaluation in the development of instructional programs. (Author)

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THE SCIENCE AND ART OF CURRICULUM DESIGN

Lauren B. Resnick

Learning Research and Development Center

University of Pittsburgh

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EA 007 273

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2

Abstract

This paper presents a model of an interactive mode for instructional research and development that might yield both curriculum products and scientific knowledge concerning learning and instruction. Curriculum development is discussed as an applied science, and as an art, using specific research and development efforts conducted at LRDC to highlight the present and potential character of the interactive model. Consideration is given to the roles of task analysis, diagnosis of learner characteristics, design of curricula and learning environments, and assessment and evaluation in the development of instructional programs.

THE SCIENCE AND ART OF CURRICULUM DESIGN

Lauren B. Resnick

Learning Research and Development Center
University of Pittsburgh

Education, broadly viewed, is any process that results in expanded knowledge and competence for those who engage in it. Typically, we think of education as going on in certain institutions--schools, colleges, training centers--but in fact the educational process is not limited to such institutions. It can, and does, occur in virtually all life encounters, in unplanned as well as planned ways.

Curriculum, by contrast, constitutes a planned intervention for the purpose of education. A curriculum can be thought of as a series of activities explicitly designed to change the knowledge and competence of those who engage in it. Whenever an educational experience is planned, whenever explicit efforts are made to optimize learning and development, a curriculum is being designed. The curriculum may be tight or fluid in style; it may specify activities in great detail or only in general outline; the instructor may control most moves or much may be left to learners. Whatever the particular strategy or ideology of education employed, it is appropriate to speak of a curriculum whenever education is not simply left to chance.

In some societies, the largest part of the individual's education is "informal" in the sense that it takes place in the context of normal work or social activity (Scribner & Cole, 1973). While some verbal instruction or demonstration may be offered, this is always done in a concrete context; thus relatively little linguistic and symbolic activity is required, and direct application to culturally relevant tasks is assumed. In a society

such as ours, however, which demands complex symbolic abilities and flexibility in applying them across a range of contexts, learning would be too inefficient without some planned educational intervention. Completely "informal" learning would be too context-tied to permit the flexible applications demanded in an industrialized environment. Environments explicitly designed for learning are therefore necessary in our society. Such environments are designed to convey both general cultural skills such as literacy, mathematics, or reasoning, and specific knowledge or technical competence. They are also, in principle, designed to convey such skills and knowledge reliably, i.e., in a manner that assures individuals the possibility of learning. The design of environments for learning, and of components of these environments, is the task of curriculum design.

Curriculum Design as Applied Science

Curriculum design can be viewed as a special case of engineering or applied science. So viewed, it becomes pertinent to ask what the scientific basis for design in the curriculum domain is, and how that scientific base interacts with the practice of design. The dominant view of the relationship between science and social applications holds that science produces general principles or laws, and these are studied by individuals--engineers--who apply the laws to practical problems. According to this model, which is schematized in Figure 1, the flow of information is unidirectional. Scientists provide information to technologists, but technologists do not provide information to scientists. Furthermore, technologists do not even participate actively in providing questions for scientists to work on. Rather, scientific activity responds primarily to questions generated by previous theoretical research. Thus, if the scientist ever leaves the laboratory, it is to give "advice" to engineers or to translate his findings into forms understandable to a wider audience. The scientist is not,

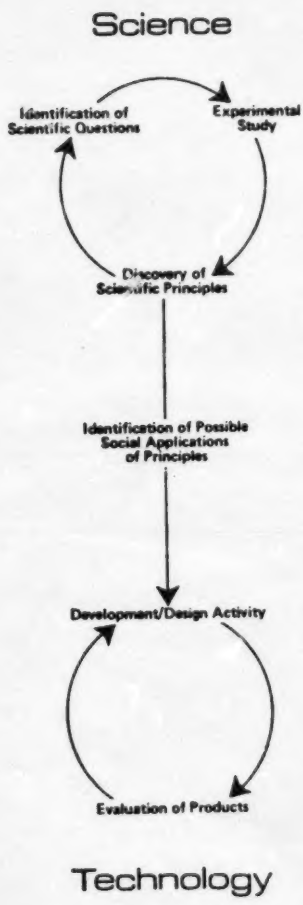

Figure 1. An undirectional flow of information between science and technology.

according to this view, directly responsible for what is done with his principles. He is not expected to study directly the social outcomes of his work; he is responsible only for producing knowledge.

Probably no one actually engaged in scientific or technological work has ever really believed in the unidirectional model of information flow. When wartime exigencies demanded technological applications, physical scientists organized themselves into special working groups, focusing on technological outputs yet yielding major new scientific knowledge. The hot and cold war conditions of the 1940s and 1950s probably only highlighted the extent to which science normally feeds upon technological demand.

In education, the question of the relationship of science to technology has barely begun to be asked. In a general way, people working at the technological, or design, end of the continuum, i.e., in instructional development, have become aware of the failure of the unidirectional model of science and technology. Rarely in their experience have principles from psychology or the social sciences been applicable in direct form to the problems of instruction. At the least, translation has been needed. Sometimes the principles themselves have seemed so far from practical concerns that developers have felt the need for research deriving from their own questions rather than from the theoretical questions of the laboratory or basic scientist. But mechanisms even for communicating design-oriented questions have been lacking, and scientists in education's "base disciplines" have, until quite recently, remained quite aloof from questions of application.

Occasionally, experimental psychologists seriously attempting to probe the relevance of their own and their colleagues' work to social affairs have reached conclusions similar to those of the designers. An interesting case in point is William Estes' (1970) recent survey of several decades of research on learning. Estes examined this research for what it could offer

as guidelines in the design of instructional programs for individuals with learning disabilities. He explicitly sought empirically validated relationships between learning, as studied in the experimental laboratory, and individual differences in mental capacity. Estes concluded that although a few encouraging developments in both theory and application could be noted, "contacts between learning theory and the empirical study of mental development have been sparse and unsystematic" (p. 187). He pointed out, further, that where progress had been made, it was generally with respect to the severely retarded--i.e., the most socially conspicuous educational failures. This concentration on a specific population meant that little had been learned about fostering higher cognitive processes (see also Estes, in press).

A few psychologists whose careers have moved relatively freely between basic research and applied concerns have addressed the question of the possibilities for a science of instructional design. Bruner (1964) has pointed out that a theory of instruction must be prescriptive in the sense of providing rules for effective ways of bringing about desired learning effects. Atkinson, in several papers (see Atkinson, Fletcher, Lindsay, Campbell, & Barr, 1973; Groen & Atkinson, 1966), has described procedures for "optimizing" learning outcomes by varying parameters of time, item selection, and other variables in relation to student characteristics. Suppes and his colleagues (Suppes, Jerman, & Briar, 1968; Suppes & Morningstar, 1972) have devoted intensive study to the details of cognitive performance on school tasks, using data from ongoing computer-assisted instruction in arithmetic.

Addressing the question of design in general, Simon (1969), in The Sciences of the Artificial, has considered what the requirements for a science of design would be and in what ways such a science would differ from the sciences of natural events. Design, Simon argues, is concerned with more than description and explanation. It is concerned with construction of artifices (hence "sciences of the artificial") to meet goals. This is done,

in general terms, by adapting the substance and organization of the artifact to the surroundings in which it operates. Applying Simon's analysis to education, the artifact is the curriculum or instructional environment, including materials and instructions for what to do with them. The "surrounding" for an instructional program, the condition that must be understood in order to design effective artifacts, is the nature of the learner, both as an individual and as a member of a social group and culture. A science of instructional design, following this general conception, would involve the study of instructional materials and/or educational environments, the study of the learner, and the study of how the learner and the educational artifact interact, particularly how modifications of the instructional artifacts change the nature of this interaction.

These considerations suggest that a new conception of the relationship between science and technology, in education as elsewhere, is required. This conception must allow for a more symmetrical relationship between basic research and social application, thus forcing science into active contact with the problems of design. Without such contact, science will continue to take its questions as well as its methods from prior theory, and its findings will probably continue to be so distant from practical concerns as to offer little guidance to the designer. To correct this state of affairs, to bring science and design--in the present case, psychological science and instructional design--into fruitful interaction with one another, it is necessary to abandon the unidirectional model of the flow of information between science and technology and substitute an interactive model.

Figure 2 suggests what is meant. The science-to-technology information flow is complemented by a technology-to-science flow; communication is bidirectional. Science continues to use its carefully controlled methodologies and to pursue questions of data or theory that arise in the course of such research, but some of its questions are now drawn from attempts at social application, from attempts to design products or

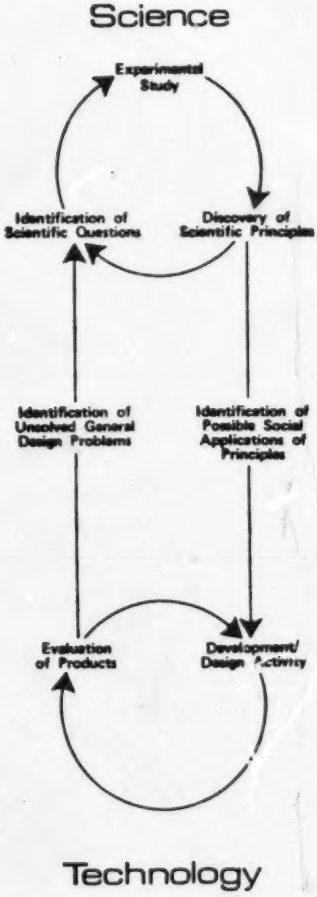

Figure 2. An interactive model of the relation between science and technology.

environments to meet social needs. Similarly, design technology still draws its principles from science, and it still depends heavily upon a cycle of observation, test, and revision that is needed for honing and sharpening its products. However, technology now takes on a further function. Its products and the accumulating data on their functioning can be searched for patterns and questions that seem general to a number of products rather than specific to any one. These are the observations that provide stimulus for further scientific work; they are the questions that keep scientific research in productive touch with problems of design and application.

The preceding comments on the general nature of curriculum development as design and applied science give the setting within which the description and discussion of particular strategies of curriculum development which follow should be interpreted. In the following sections, I will describe several curriculum design efforts with which I have been associated that can serve as illustrations of how science and curriculum design can interact. All are projects undertaken over the past ten years by various groups within the Learning Research and Development Center (LRDC) at the University of Pittsburgh. Extensive reports on each of the projects are available and will be cited throughout the discussion, but only brief discussions will be possible in the course of this paper.

Throughout the paper, but only occasionally expressed, another set of assumptions will operate. Curriculum design, like design in all other fields, contains elements of both science and art. Instructional design is scientific to the extent that it consciously applies validated principles of the natural and social sciences to problems of educational intervention and to the extent that it develops and uses systematic methods for testing its products and revising them on the basis of performance. It is artistic to the extent that inventiveness and intuition are used in initial instructional development, and further, to the extent that aesthetic criteria play a role in judging the final products. The relationship between disciplined science

and artful design should become clearer as some of LRDC's curriculum design efforts are described; the possibility and desirability of these relationships will receive more explicit treatment in a later section.

Each of the curriculum design examples discussed is drawn from the subject matter of the elementary or preschool and is thus closely allied with developmental and child psychology, as well as with learning psychology. Further, all have shared a common commitment to developing programs of education that are adaptive to individual needs and abilities of learners. They thus have many specific features in common, such as an emphasis on diagnostic description of children's capabilities and some reliance on self-instructional material. Equally important for the present discussion, each curriculum has been developed with a strong degree of conscious attention to deriving general principles from design activity by studying curriculum products and their functioning in schools for clues to general principles of instruction as well as for effectiveness in meeting an immediate goal.

The curriculum design projects will be discussed not in their chronological order of development, but rather in the context of a set of considerations that seems to be central both to the development of instructional products and to the development of a theory of instructional design. These considerations were outlined in an earlier paper by Glaser and Resnick (1972). They are: (a) analysis of the task properties of the knowledge domain or, more practically, a description of the state of knowledge to be achieved; (b) diagnosis of the characteristics of the learners, i.e., description of the learner's initial state; (c) actions that can be taken or conditions that can be implemented to transform the initial state, i.e., design of the curriculum or instructional environment; (d) assessment of specific instructional effects; and (e) evaluation of generalized learning outcomes.

What Is to be Learned: The Analysis of Tasks

Classically, specification of what is to be learned has been the prime requisite for the design of curriculum. It has often been assumed that experts in any domain make the best developers of curricula. It was this point of view that lay, in part, behind the major curriculum reform movements of the 1950s and early 1960s. Scientists and other scholars, working at the frontiers of their disciplines, began to examine the content of school curricula and found it not to reflect their own understanding of the disciplines. The new curricula of the period (PSSC and SMSG, for example) were designed to present to novices, sometimes even in the elementary school, the concepts considered essential by experts in the disciplines.

Instructional design work itself has made it increasingly clear that while expert knowledge of the domain to be taught is certainly required for curriculum design, the subject-matter expert alone will rarely be able to provide a description of his competence in a form that can guide development for novices. Bruner (1964) pointed this out when he stressed the need to transform the expert's version of concepts into forms comprehensible to younger or less experienced individuals rather than presenting them in their original form. More recently, Glaser (1973) has emphasized a distinction between knowledge structures as organized for the expert to facilitate use of previously learned bodies of knowledge and those organized for the learner to facilitate acquisition of competence. The expert's inability to describe fully the bases of his own performance has also emerged in recent work in cognitive psychology, work that attempts to simulate the performance of expert performers of complex tasks (e.g., Newell & Simon, 1971). Skilled performers of a task cannot always describe well <u>what</u> they know; even more rarely can they describe the psychological processes called upon when they <u>use</u> their knowledge; and they are further still, in most cases, from being able to describe how they acquired their expertise--how they changed from novices to experts.

Task Analysis in Cognitive-Developmental Psychology

A distinction between skilled performance and developing competence has been stressed as a general scientific observation by many developmental psychologists, and study and description of children's competence in various kinds of tasks have been a major focus of cognitive-developmental psychology over at least the past decade. The tasks studied have frequently been drawn from Piaget's pioneering work and sometimes from traditional adult laboratory learning tasks, now reexamined as developmental phenomena. Occasionally, developmental study of phenomena directly related to school tasks such as reading has been undertaken (e.g., Gibson, 1965). The results of this large body of research in developmental psychology serve to highlight the task facing curriculum designers: The research makes it evident that adult concepts and skills are not "born" full-blown, that children--and presumably, learners of all ages--pass through successive stages of understanding and ability en route to what we view as mature competence, and that each such stage has a kind of logic to it. "Unskilled" performances make sense if understood in their own terms; further, they are the route to competence, a route that must be probed and clarified if instruction is to optimally match the developing capabilities of learners.

Influential as this research has been in highlighting the general question of how changes in competence occur, the strategies and assumptions of most research in developmental psychology make it difficult to apply the findings directly to instructional problems. Most developmental research is expressly "non-interventionist." The aim is to discover and describe "natural" sequences of development. There operates in this work an often unspoken but nonetheless powerful driving assumption that the sequences thus discovered will be universal and environment-independent. "General experience" rather than any specific set of environmental interactions is thought to produce developmental changes (cf. Kohlberg, 1968; Rohwer, 1971). What is implied but rarely tested explicitly in developmental research is that natural environments are similar in crucial ways, and that

they will therefore facilitate development of the same kind. Recent cross-cultural work (see Cole, Gay, Glick, & Sharp, 1971; Goodnow, in press; Pick, Note 1) is beginning to substantiate the long-argued suggestion that environments may differ quite radically in their demands and that adult cognitive competence and style vary accordingly. But developmental psychology as a whole still lacks a theory and even a good set of descriptors of the environment. Thus, it is difficult to cull from developmental theory any but the most general guidelines for design of environments specifically intended to bring about changes in competence.

Rational Task Analysis and Learning Hierarchies

What is needed for purposes of instructional design is a description of desired educational outcomes in a form that specifies the psychological processes called upon in skilled performance and also suggests less sophisticated organizations of skill and knowledge that are capable of leading to or producing skilled performance. In other words, we need analyses of learning goals that specify both the nature of competent task performance and simpler tasks that will facilitate learning. These "facilitative" tasks, organized and sequenced to maximize the match between current abilities and new demands, will constitute a curriculum (cf. Hunt, 1961, for a discussion of this matching process from a different theoretical viewpoint).

Over several years of work in designing an early learning program for preschool and primary grade children (The Primary Education Project; see Resnick, Wang, & Rosner, in press), we have developed a method of task analysis explicitly designed to meet these objectives. The strategy yields hierarchies of tasks similar to those proposed by Gagné (1962, 1968), but with more specification of the actual processes involved in performance. A detailed description of the method as applied to an introductory mathematics curriculum appears in Resnick, Wang, and Kaplan (1973). Figure 3 illustrates the process. Each box in the figure describes the

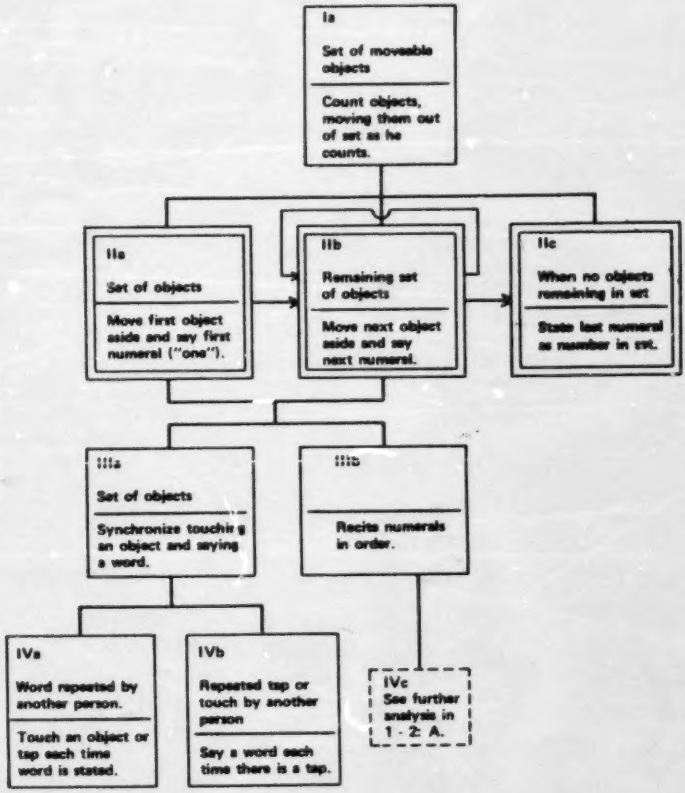
Ia
Set of moveable objects
Count objects, moving them out of set as he counts.
IIa
Set of objects
Move first object aside and say first numeral ("one").
IIb
Remaining set of objects
Move next object aside and say next numeral.
IIc
When no objects remaining in set
State last numeral as number in set.
IIIa
Set of objects
Synchronize touching an object and saying a word.
IIIb
Recite numerals in order.
IVa
Word repeated by another person.
Touch an object or tap each time word is stated.
IVb
Repeated tap or touch by another person
Say a word each time there is a tap.
IVc
See further analysis in 1 - 2: A.

Figure 3. Task analysis of an early mathematics objective. (From "Task Analysis in Curriculum Design: A Hierarchically Sequenced Introductory Mathematics Curriculum" by L.B. Resnick, M.C. Wang, and J. Kaplan, *Journal of Applied Behavior Analysis*, 1973, *6*, (4), 679 - 710, Figure 1 - 2:B.)

situation as presented to the child and the child's expected response. Thus the top box (Ia) should be read, "Given a set a moveable objects, the child can count objects, moving them out of the set as he counts." This provides verbal specification of the task to be analyzed. The first step in performing an analysis is to describe in as much detail as possible the actual steps involved in skilled performance--i.e., the "components" of the task. The results of this analysis are shown in level II of the figure. Once the components are identified, each is considered separately, and abilities that are prerequisite to or facilitative of learning the components are identified. For example, the tasks described in IVa and IVb facilitate learning IIIa, which in turn facilitates learning IIa and IIb. Analysis of this kind can result in charts showing several levels of tasks with complex interrelationships among them (shown in the figure by connecting lines). Frequently, when a set of tasks from a single curriculum domain are being analyzed, one task in the set to be analyzed appears as a prerequisite to another in the set. These relationships provide the basis for sequencing the separate tasks of a curriculum in a way that will optimize transfer and maximize the likelihood of success in learning. Frequently, too, the same abilities appear as prerequisite to several different tasks. In this case a generalized ability has been identified, one to which special diagnostic or instructional attention should probably be devoted in order to optimize instructional effectiveness and efficiency for learners of varying characteristics.

Although the example given here is for a very simple task, counting a set of moveable objects, the strategy of analysis is a general one and can be applied to tasks in various domains. The level of specificity--that is, the fineness of detail with which given tasks are analyzed--depends upon the task and the population for whom instruction is being designed. As a general rule, no further prerequisites would be specified when a level of behavior is reached that can be assumed in most of the student population in question. Further, the initial analysis should describe task components

at a level of detail consonant with what one expects is already a reasonably well organized behavior in the learner's repertoire. Even in a curriculum for kindergarten children, as in the present example, much is left unspecified. For example, it is assumed (Box IIa) that the child will be able to recognize a grouping of separate elements. Similarly, it is assumed that the motor acts of moving an object or saying a word are already organized and need not be further analyzed.

We have used these strategies of task analysis in developing curricula for a variety of preschool and primary grade programs (see Beck & Mitroff, 1972; Resnick et al., in press; Lindvall, Note 2). In each case, careful attention has been devoted to validation of the analyses either through special validation studies (see Resnick, 1973, for a general discussion of validation strategies) or through careful study of the curriculum itself (see Resnick et al., 1973). These studies not only serve to validate proposed curriculum sequences, but also yield basic information on natural sequences of development (e.g., Wang, 1973; Wang, Resnick, & Boozer, 1972) and on the nature of transfer relationships among hierarchically related tasks (e.g., Caruso & Resnick, 1972; Resnick, Siegel, & Kresh, 1971). Thus, they exemplify a form of interactive research and development, cases in which efforts to develop optimal curricula have generated research on questions of basic scientific interest.

Information Processing Analyses

The analyses just described can be appropriately characterized as informal "process models" of performance at different stages of expertise. As process models, they specify hypothesized components and temporal organization of performance and attempt to identify the underlying memory, perceptual, linguistic, and other processes that are embedded in the more complex tasks. More formal methods of task analysis, drawn largely from the work of current information processing psychology, also

deserve consideration as possible bases for future instructional work. Formalized task analyses require both more completely specified performance models than the ones we have used in curriculum development up to now and more precise empirical validation. The most demanding current criterion for a complete performance model is that it be written as a computer program that is capable of performing the task. A program of this kind encourages precision in modeling (computers take their instructions quite literally) but can be written so as to engage in quite sophisticated "heuristic" behaviors (see Newell & Simon, 1971).

Technologies for computer modeling of this kind exist. It would be a tedious but not highly inventive task to turn each of the many informal process models we have written into programs that assured us of the completeness--in this technical sense--of our analysis. With that task accomplished, we would still need to test the programs as models of human performance. Our work on validation of learning hierarchies has provided an initial test of these models. The models are accurate enough to predict well the transfer of relations holding between tasks and the general order of acquisition. However, a variety of specific performances might produce the same general patterns of sequence and transfer; more rigorous methods of validation are required in order to lend credence to the details of any given process model. Methods for such validation include detailed analysis of individual verbal and behavioral protocols, study of differences in reaction times for slight variants of a task, analysis of frequency and type of errors, and so forth--in short, virtually the entire range of methods now in use in the field of cognitive psychology.

Clearly the use of formalized models is expensive, and consideration must be given to when the added cost of formal specification and empirical study is likely to add enough instructional power to make the effort worthwhile. In subject-matter domains where much is known--where successful examples of instruction abound, where the subject matter has an inner logic

that lends strong face validity to hypothesized analyses--the added effort of formalized analysis may have relatively small direct payoff for instruction. Where little is known, where even strong hypotheses concerning actual process are difficult to find, much may be gained through the discipline of formal analysis. Many unlikely or less than optimal paths for instruction may be eliminated, and strategies likely to be effective may be suggested.

A contrast between analysis of mathematics and reading tasks at different stages may help to make this point. In a general sense, mathematics--especially early mathematics of the kind we have studied and analyzed--presents relatively few ambiguities. The subject matter is a closed logical system, within which informal analyses are quite likely to reflect skilled performance reasonably faithfully and thus to guide instructional design effectively. The same is largely true of early reading, where letter-sound correspondences are relatively easily specified and ordered. By contrast, it is very difficult to develop process descriptions for language comprehension and for advanced mathematical thinking. Many competing analyses are possible. Especially in language, the subject-matter domain is "open" and highly dependent on context, on past experience, and on details of the task as presented. It is by now quite widely agreed (see Miller, in press) that comprehension is not a simple linear process, that it involves use of redundancy in the structure of the language and a search for meaning--in short, it is a very complex cognitive process. For this kind of subject matter, formal process analyses and empirical tests are likely to have especially high payoff. At present, for example, there exists no generally accepted model of how a prose passage is comprehended when read, of the processes involved in taking and interpreting information from a text. In this situation, much may be gained through the disciplining effort of formalized task analysis and related empirical research leading to the development of psychological models of comprehension processes.

One example of a case where a formal analysis of an academic task has led to some unusual and potentially highly productive instructional design comes from spelling. An original model for how children spell was written by Simon and Simon (1973). This was a formal model in the sense that it (a) took into account existing data on the structure of the sound-symbol correspondences of the language and the typical errors made by children in spelling, (b) was written as a computer program, and (c) was validated, in part, on the basis of the ability of the program to match actual performance both in terms of correct spellings generated and in terms of the kinds of errors typically produced. Spelling programs that embody some of the processes identified in the Simon and Simon analysis have been written under the direction of Karen Block at the Learning Research and Development Center. These spelling lessons, which are computer-based and utilize the special responsive characteristics of the computer, include practice in generating alternative spellings for given sounds, in sorting spellings according to patterns used to represent the same sound, and in choosing among alternative spellings. This work virtually embodies the interactive mode of curriculum design. The initial analysis of spelling was motivated by an applied instructional need. The resulting model provided the basis for lesson design, which in turn will provide one of the pieces of converging evidence needed to validate the model itself. If children trained in the processes identified in the model improve in spelling and continue to match the program in terms of quality as well as correctness of output over successive levels of competence, validation of the model will have been provided in the course of instruction itself.

Formal and empirical process analyses are likely to yield much instructional power when the aim is to identify and find ways of [illegible]structing what we call "generative skills"--basic abilities that are used in a variety of learning and other performance situations. Current cognitive psychological theory is pointing with increasing consensus to the existence of

certain basic processes--for example, memory, perception, inference strategies--that are quite general in human functioning and thus would produce generalized learning abilities were we to find ways of enhancing them. These abilities are embedded in academic tasks and in on-the-job performance tasks of various kinds. Some of these abilities appear to be tapped indirectly by the kinds of tasks that are found in most widely used intelligence and aptitude tests. But the abilities are deeply embedded; they are not visible in cursory forms of task analysis as, for example, in job analysis techniques, and they require complex study to be detected and understood. It seems likely that formal task analysis procedures will prove to be a very effective means of identifying generative skills and suggesting methods for their instruction. The power of such analyses in the instructional design domain remains only a promise at this time, but it is a promise worth serious investigation. (For an early example of some possibilities along these lines, see Resnick & Glaser, in press; for a more extended discussion of the general role of information processing task analysis in instructional design, see Resnick, in press.)

Diagnosis of Learner Characteristics

Closely allied to the problem of describing what is to be learned is the problem of describing the capabilities of the learner as he enters the learning environment. This step is crucial if curricula are to be adaptive to individual differences. It is necessary to know what the learner is like--what he can do that is directly relevant to the subject matter to be learned, what he can do that constitutes a more generalized learning-to-learn skill, what motivates him, and so on. With this knowledge in hand, it becomes possible to design curricula that adapt to these characteristics. The description of these characteristics must be in terms relevant to educational decision making. For this reason, typological descriptions generally are not useful, as compared with descriptions of specific competencies and behaviors that can be observed under specifiable conditions.

Describing individuals as highly intelligent or not so intelligent gives little guidance in what kinds of instructional treatments are most likely to be effective. The ineffectiveness of such approaches is testified to by the bulk of the literature on aptitude-treatment interactions--years of research that have yielded virtually no useable information on how to adapt instructional treatments to individual differences (Bracht, 1970; Cronbach & Snow, 1969). Thus traditional approaches to testing and differential psychology, developed and validated for purposes of selection and prediction rather than adaptive instruction, are of relatively little value in their present form. New ways of conceptualizing the nature of individual differences are required and, along with them, new ways of assessing these differences (Glaser & Nitko, 1971; also Glaser, 1972).

Describing the learner is not something that is done at the outset of instruction and then left alone until final assessment of the outcome of instruction. Rather, it must be a more or less continuous process. As he proceeds through a curriculum, the learner's capabilities change. They change in terms of both specific knowledge acquired and generalized abilities available for further learning. These changes can result either from general experience during the period coterminous with instruction or from engaging in the instruction itself. Thus, to maintain an effective curriculum over an extended period of time, it is necessary to address the problem of describing changes in the learner's capabilities as instruction progresses and to do this in a form that is useful in making decisions as to the course of succeeding instruction.

The discussion in the previous section on analysis of the subject matter has already alluded to some of the ways in which this problem can be attacked. Hierarchies of learning tasks, generated through formal or informal task analysis, provide a way of describing the learner's capabilities in terms of the tasks and underlying abilities that make up the curriculum itself. Describing which tasks an individual can already perform

within a hierarchy and which are yet to be learned tells the instructor (or the learner himself) which tasks he is likely to make progress on and which he is likely to find too difficult. Thus the learner's capabilities can be described in terms of the curriculum content itself and its underlying processes. Further, they can be described as a changing function of his progress, or lack of it, through the curriculum. The hierarchy of tasks thus serves as a map that describes both present location and possible directions of movement of any learner currently under consideration.

The Role of Criterion-Referenced Testing

Implementing this mapping function of curriculum hierarchies requires a form of testing that is explicitly designed for ongoing instructional decision making--i.e., that will help in placing individual children in the curriculum structure and provide diagnostic information for use in making specific instructional assignments. Considerable effort was devoted to developing such a testing strategy in LRDC's first major curriculum development undertaking, Individually Prescribed Instruction (IPI). A paper by Glaser (1970) outlined the major evaluation requirements for a system of education that adapted instruction to individual requirements:

1. Outcomes . . . of learning are specified in terms of observable learner performance and the conditions under which this performance is to be exercised.

2. Detailed diagnosis is made of the initial state of a learner entering a particular instructional situation.

3. Educational alternatives are provided which are adaptive to the classifications resulting from the initial student ability profiles.

4. As the student learns, his performance is monitored and continuously assessed at longer or shorter intervals appropriate to what is being taught.

5. Instruction and learning proceed in interrelated fashion, tracking the performance and selections of the student.

6. The instructional system collects information in order to improve itself, and inherent in the system's design is its capability for doing this. (pp. 29-30)

These requirements were met in IPI by elaboration and application of the notion of criterion-referenced testing (Glaser, 1963). Such tests are equivalent to "work samples" as a means of assessing job performance. Criterion-referenced tests were used to assess entering level in the curriculum sequence (placement tests), immediate mastery of individual skills as they were taught (curriculum-embedded tests), and mastery of a unit of related objectives (pre- and posttests). With younger children in the Primary Education Project (PEP) and subsequent adaptive curricula the tests were administered orally on a one-to-one basis and frequently involved the use of manipulative materials appropriate to the task and age level. These tests were used by teachers as part of the regular instructional process. The tests, along with observation of the children's activities as they worked on instructional materials, guided the teachers both in placing children in the curriculum structure and in adapting the instruction to individual needs.

Use of criterion-referenced tests in the manner described for individualized instruction raised a series of questions which in subsequent years commanded the attention of researchers within LRDC and elsewhere. One set of questions has concerned the strategy for specifying objectives and creating pools of test items that would adequately sample the specified domain. Initial test development efforts were informal and iterative: An objective was described verbally, test constructors wrote items that appeared to match the statement of the objective, the items were reviewed by the curriculum designer, and either items or stated objectives or both were revised until a consensus was reached that the test reflected the curriculum developer's intent. There was no formal procedure for specifying the objective to be tested or for sampling among test items for inclusion in the tests. Further, standards for passing and failing, mastery and

nonmastery, were informally and largely arbitrarily set in terms of passing or failing some fixed number of items on the test. A recent paper by Nitko (1974) discusses in some detail the questions posed for testing theory and practice by the increasing use of criterion-referenced tests.

Some Examples of New Approaches to Testing for Instructional Decision Making

In the case of test theory, as in the case of task analysis, serious work on theoretical questions has been prompted by the demands and the successes of instructional development. Two cases of interwoven development and research activity in testing illustrate this point. The first concerns the use of the computer as an aid in "tailored" or "adaptive" testing. It is possible, using a computer, to tailor testing to the individual's performance by limiting the number of items given to those actually needed to reach a decision and by branching to new classes of items for further diagnosis. To accomplish this, systematic rules are required both for generating items in a class and for making pass-fail decisions. The first requirement was met by an adaptation of the strategy of "item forms" (see Hively, Patterson, & Page, 1968) so that the computer could generate a large number of specific items based on a limited set of stored parameters and generation rules. Two different kinds of decision rules, one based on traditional statistical theory and the other on Bayesian theory, have been investigated. Both permit evaluation of successive "pass" and "fail" cases as they cumulate, and both allow testing to stop as soon as a reasonably certain decision is reached. This is much the way a skilled diagnostician proceeds: If the individual being tested passes several items in sequence, a positive or "mastery" decision can be made; if he fails several in sequence, a negative or "nonmastery" decision can be made; if the individual vacillates between passing and failing items, a longer period of testing is needed to reach a decision. Further detail on these theoretical investigations

and their applications to tailored testing can be found in papers by Ferguson (1969) and Hsu, Carlson, and Pingel (1974).

The second case of interest here grows out of the successful development of diagnostically oriented tests of visual and auditory skills by Jerome Rosner (1971; Rosner & Simon, 1971). The tests Rosner developed correlate positively and strongly with existing tests (in the case of visual skills) and also predict performance on related academic tasks such as beginning reading (in the case of auditory skills). They are distinguished from past tests of these skills by the fact that they are tied directly to curricula designed to teach the skills tested. Typically, tests used in predicting academic performance lose their predictive validity when the tasks appearing in the tests are directly taught. Studies conducted to date suggest that this is not the case for Rosner's tests--that instruction oriented to improving test performance can be successful and that the improved performance will be reflected on other tasks not directly taught. This kind of finding, if replicated, validates the procedure of using criterion-referenced tests as targets for instruction. It requires, however, that the tests be validated for such use--i.e., that their ability to retain predictive validity when directly taught is established. A recent working paper by Nitko (Note 3) discusses the kind of validation studies necessary for criterion-referenced tests that are to be used as an integral part of instruction. Such validation studies represent a potential new methodology in test construction.

Design of Instructional Materials and Environments

A major and important aspect of curriculum design work has been completed when task analysis and diagnostic instruments are available. The task analysis translates general statements about curriculum content into specific concepts and skills to be taught and, in many cases, also provides a sequential structure for the content. Criterion-referenced

diagnostic tests, in addition to their use in instructional decision making, serve as working definitions of the specific content.

Yet despite the structure imposed by task analysis and criterion-referenced tests, there is a large, and largely intuitive, leap to be made from these specifications to an interesting and effective instructional program. Examination of "systems" approaches to curriculum development will reveal that there is no good set of prescriptions available for designing instructional materials. Instead, there is heavy dependence on a cycle of iterative development and testing. This process serves to validate the effectiveness of intuitive translations of curriculum specifications into instructional procedures; it cannot, however, substitute for artful design work at the outset, for tests will only reveal successes and failures, not prescribe alternative strategies. The actual design of instructional materials or instructional environments, then, is a matter of art as well as science and requires a special facility for combining intuitive and scientific knowledge.

Design of Adaptive Learning Environments

The need for an effective combination of art and science becomes especially apparent when one is concerned with designing entire environments for learning rather than the separate components or instructional materials. A "curriculum" is often thought to consist of the "lessons" that students will encounter --the "things" of instruction. Only rarely in discussions of curriculum does one find much explicit treatment of the role of the total environment in promoting (or hindering) learning. Yet the social context within which instructional materials are used can enhance or diminish their effectiveness to an extraordinary degree and, conversely, instructional materials can encourage or discourage certain kinds of social expectations and behaviors that are essential to learning.

The history of LRDC's work in designing adaptive educational programs illustrates the importance of the general environment as an instructional variable and the ways in which instructional materials and social environments for learning interact with one another. IPI began as an attempt to apply general principles of individualized instruction to an entire elementary school. It was not a lesson design project, but rather a school design project, with the necessity for curriculum development following from a conception of how a school adaptive to individual differences ought to run.

The goal of IPI was to develop a form of instruction that would embody principles of individualization in a form that was disseminable to and useable in a broad array of public schools. Individualization had a long history in educational theory and in relatively isolated instructional practice, but in the early 1960s it had not been shown to be a principle that could work in practice outside of a few specially staffed demonstration schools. To translate individualization into a widely useable concept, it seemed necessary to provide a manageable means for teachers to diagnose children's strengths and needs in any given learning domain and then to provide instruction suitable to these diagnoses.

Adapting Existing Materials to an Individualized Environment

Initial efforts of the IPI project were directed at identifying and organizing existing instructional materials for individualized use rather than designing new lessons or related material. Thus, in keeping with the principles discussed earlier, work proceeded on specification and sequencing of objectives and on design of tests for monitoring student progress. The intent was to use the tests diagnostically and then make assignments in a variety of texts and workbooks to match individual needs. These early efforts made clear the extent to which instructional materials and instructional environments were interdependent. The existing textbooks

had not been written for an individualized school, and it proved more difficult than expected to key existing materials to IPI sequences of objectives and tests. It was not easy to find in the texts lessons that fully taught new concepts, since it was generally expected that these would be presented by the teacher in group instruction and that the exercises engaged in by children would serve largely as practice. Further, close analysis revealed that most textbook lessons confounded the teaching of several concepts or skills. The lessons were often designed simply to expose children to concepts rather than to assure mastery of those concepts. These features of the textbook materials discouraged independent work by children and thus implicitly encouraged the continuation of teacher-oriented instructional practice. In a public school, even one that enjoyed a greater than usual number of paraprofessional aides, this inevitably meant group instruction and expository rather than participatory instructional styles--in short, a less than optimally adaptive environment.

Designing Instructional Materials to Shape the Environment

These observations, based on trials in an entire elementary school, led to increased attention to the development of instructional materials themselves. The IPI and PEP curricula, as they are publicly known and used today, are the results of this "materials development" phase of LRDC's work. These curricula continue to embody a general system for managing structured individualized teaching. Heavy emphasis is placed on the specification of learning objectives in observable form and on testing that allows placement of children in the various curriculum sequences according to their actual level of mastery at a particular time. Emphasis is also placed on keying instructional materials to tests so that assignments can be matched to children's performance on these tests. Finally, tests and instructional materials are arranged in such a way that children can access and use them on their own or with the help of paraprofessional aides, thus permitting them to work independently of the teacher's moment-

to-moment direction and with a considerable degree of self-management. The result in practice has been a substantial difference in the rates at which children progress through the curriculum (Glaser, 1968; Resnick et al., 1973). The program has also resulted in some substantial changes in social interaction patterns in the classroom. In various studies teachers have been observed to engage in more instructional (as opposed to management or discipline-oriented) interactions with children and more of these have involved individual children rather than groups. There are more student-initiated communications, and there is generally less teacher-oriented behavior on the part of the children. Thus, this instructional design effort has demonstrated that substantial amounts of individualization, at least with respect to rate of learning, are possible in the public school classroom, given appropriate design and organization of the instructional materials. It has also made it clear that such individualization, if seriously pursued, has potentially profound implications for the social organization of the classroom.

Designs for Organizing and Running an Adaptive Classroom

LRDC's curriculum development efforts led to the realization that although individualized instructional materials encouraged adaptation to individual differences, they could not, in and of themselves, ensure it. Indeed, quite new forms of classroom organization and teacher behavior were required if the curricula were to function optimally. With 25 or so children working on almost as many different activities, the traditional model of the teacher demonstrating or explaining to groups of children could not work. Some teachers, given the instructional materials and the help of an aide for administering or scoring the various tests that formed part of the program, invented for themselves a way of managing this complex social environment. Others foundered.

Observation of and consultation with teachers who were successful in using the program eventually led to the development of a model for classroom management and organization. The model specified open display of instructional materials and a coding system that would allow even a very young child to interpret instructions on a "ticket" that specified which activities he should engage in. It also specified the various teaching functions that needed to be carried out in the individualized classroom: testing, tutoring individuals, instructing small groups, and "traveling" among the children as they worked to help, to encourage, and to observe. Traveling was the function most foreign to teachers used to traditional classroom organizations, and new teachers needed considerable help in learning the most effective ways of behaving as they circulated in the classroom. Teacher training strategies had to be developed for this and related forms of behavior (see Leinhardt, 1973). As the program was disseminated, these new modes of interaction became incorporated as a vital part of the definition of the program, thus broadening the "curriculum" to include explicitly the social environment created by the teacher (see Resnick et al., in press). This broadened definition of curriculum, which includes goals of self-direction and general learning (inquiry) skills and incorporates strategies for managing a classroom in which complex combinations of assigned and child-selected activities occur simultaneously, is also embodied in LRDC's Individualized Science program (see Klopfer & Champagne, 1974).

Adapting Curricula to Aptitudes

Observation of the IPI programs in use and study of the cumulating test data on individual children made it increasingly evident that for some individuals, assumptions the curriculum made concerning their abilities upon entering the program were incorrect. In common with other primary grade programs, IPI assumed a wide range of specific abilities and general "aptitudes" upon entry to school. Ability to focus attention in a

directed way, to analyze visual and auditory inputs, to hold material in memory in the face of competing stimulation--all of these are abilities called upon in a large number of different school tasks. They are thus examples of the learning-to-learn abilities discussed earlier in this paper. They are aptitudes that must be explicitly taken into account in a fully adaptive curriculum that aims to assure mastery for all children (cf. Glaser, 1972).

Two kinds of adaptation to individual aptitudes must be given careful consideration in instructional design. One is the possibility of teaching aptitudes directly so as to insure that all individuals entering a given instructional program have at their command the basic process abilities assumed by that program. The second is to design alternative instructional treatments to match or cater to the differences in entering aptitudes within any given population. We have explored both of these approaches.

The notion that aptitudes may be teachable is relatively new both in psychological theory and in educational thought (see Glaser & Resnick, 1972, for a review of literature in the area). One of the few aptitude domains that has been studied in this way in the past is that of perceptual-motor abilities. The relationship of visual and auditory abilities to early school performance has long been recognized, and over the years considerable effort has been devoted to training children recognized as having perceptual-motor dysfunctions. Rosner's work in this area, mentioned earlier, extended this concern to preschool and kindergarten children and was aimed at preparing them for the academic demands of reading and mathematics instruction rather than at offering remedial help once a cycle of failure had manifested itself. In addition, Rosner engaged in both systematic analysis and detailed, iterative testing of instructional materials in order to come up with a set of activities that would train the underlying processes of visual and auditory analysis. The result, developed over a period of about five years, is a set of teaching programs for visual and auditory analysis

skills (Rosner, 1973) that are capable of raising scores on standardized "aptitude tests" and also show transfer to learning early reading and mathematics (Rosner, 1972).

While programs that teach basic aptitudes are extremely powerful because of their generative relationship to other learning, they are not always available or useable. When aptitudes cannot be taught, adaptive education requires that instruction in other programs be matched to the learner's abilities. Our work on modification of the initial IPI reading program illustrates this form of adaptation. The initial program was based on a commercial programmed reading series to which we had added instructional tapes for teaching new sounds and for a variety of additional story reading activities. The program was a phonetically oriented one and it assumed, after the introductory unit, that children taught a new letter-sound relationship would be able to apply it to the "sounding out" of new words. Yet a crucial part of the sounding-out process was never really taught. That part is known as "blending." The program we used, like most available beginning reading programs, told children to blend ("slide the sounds together"; "say it faster") but never taught them how. Some children, presumably those with better developed auditory skills, invented a procedure; others did not and as a result continued to have difficulty with later units in the reading program.

To meet the needs of these children for more explicit instruction, an introductory component was added to the reading program on a trial basis. This component taught children explicit strategies for blending sounds. The results were excellent: There was close to a 100% success rate in learning the blending process, and performance on standardized as well as curriculum-specific reading tests improved. This blending strategy is now being incorporated into a beginning reading system that combines a variety to types of instruction into a highly adaptive program (see Beck & Mitroff, 1972). This form of adaptation to aptitudes offers special support to the learner in an area in which he is weak in the context of a regular subject-

matter program. It is a strategy that needs substantial further investigation. One potential effect, suggested by occasional studies in the past (e.g., Meuris, 1970) but never seriously investigated in the context of curriculum development, is that the aptitude itself may be increased by subject-matter instruction of certain kinds.

The examples discussed here are representative of design strategies that incorporate long-term study of curriculum effects as well as short-term trials of lessons. New approaches to instruction rather than "patching" of existing programs are often suggested by such study. These long-term studies are costly on their face, but may be inexpensive when considered in terms of ultimate effectiveness. The general strategy is to design and implement a curriculum relatively quickly, building on the best available knowledge combined with a good measure of artistry and invention. Once a curriculum is operating, the needs of the current population of students are being met while at the same time a natural laboratory is formed in which research can proceed. In this way the cost of successive program development is spread over several years of actual use. Meanwhile, research and observation focused on actual instructional effects can proceed, furnishing another example of an interactive research and development mode.

Assessment and Evaluation

Earlier sections of this paper have already alluded to the kinds of strategies we have found most useful in assessment of specific instructional effects. The use of criterion-referenced tests as a part of the curriculum has made it easy to follow the progress of children and thus to test the effectiveness of our program in teaching its defined content. Papers by Glaser (1967) and Resnick et al. (1973) describe the way in which this monitoring process can be used in study and revision of curricula and give examples of the kind of data collected.

Other studies (e.g., Resnick & Wang, 1974) have shown a substantial relationship between position within the curriculum hierarchy and performance on standardized tests, thus offering an additional validation of criterion-referenced tests and the general program strategy.

Not all objectives of instruction lend themselves easily to frequent criterion-referenced testing. This seems to be the case for domains such as reading comprehension, scientific inquiry, problem solving, and other abilities that are complex and heuristic in character. It is likely that such abilities develop over relatively long periods of time and that the cumulative effect of the total environment--instructional materials, questions raised by peers and teachers, the opportunity to risk new tries--rather than any specific set of lessons produces the effect. This raises a new set of tasks for those concerned with assessment of instructional effects. If all assessment is left for the long term there is no way of determining which aspects of an instructional program produced the effects observed nor any way of adapting instructional strategies as work proceeds. New methods of assessment, probably involving observation of the educational process rather than tests, will need to be developed. Again, though costly, such development work is likely to yield rich dividends in educational practice and theory by providing more systematic and useable knowledge about how generative learning skills develop and how environments for teaching them can be designed.

Evaluation in the Field

Ultimately, the value of any curriculum depends upon how it works in the field away from the watchful and sympathetic ministrations of its developers. Classically, the pattern for field evaluations has been to contrast settings using some program with settings not using it. Such evaluations have rarely yielded clear results, nor have they ever been very useful in helping to determine which elements of a program were crucial to

maintain and which could be dropped or modified. One reason for the lack of clear contrast effects has been suggested earlier in this paper: No two teachers implement a program in quite the same way. In order to interpret field test data, it is important to know how the program has been implemented in each site studied and to include implementation data in interpreting outcome data.

Cooley (1971) has outlined a general strategy for using implementation data in field evaluation of curriculum innovations and the method has been applied both to LRDC's programs and to a portion of the Follow Through national data (see Leinhardt, 1974a, 1974b). This methodology, along with related strategies that use implementation measures as part of an evaluation study, is of substantial interest for its contribution to interactive research and development in curriculum. Not only does it yield more interpretable information on outcomes in the field, it also serves to test--or generate--hypotheses concerning which instructional effects are the most powerful. It serves, in other words, to abstract from specific programs the features that contribute most to learning outcomes. This information in turn offers guidance in new curriculum development that may incorporate important common features into programs quite different in other respects.

Conclusion

This paper began with a discussion of curriculum design as an applied science. The succeeding sections focused largely on describing the present and potential character of an interactive mode of instructional research and development that might yield both curriculum products and scientific knowledge concerning learning and instruction. It remains to make more explicit the assumptions noted earlier concerning the relationships between art and science. By way of conclusion, I turn now to a consideration of the place of art in the science of curriculum design.

Various fields of design have differed in the relative emphasis placed on scientific and aesthetic principles and criteria in their work. In some fields of design--for example, architecture--the artistic function is explicitly recognized and accorded status. The designer's function is not simply to apply knowledge produced elsewhere in a mechanical and deterministic fashion, but to use this information to create a product that is aesthetically pleasing as well as functional and economical. Architects, however, cannot function without knowledge of a significant amount of basic physical science as well as knowledge of available materials and their properties. Thus, the profession must also qualify as an applied science.

In fields where aesthetic criteria for the finished products are less pronounced, artistry in creation tends to be played down, and systematic procedures for developing and evaluating products are stressed. This is the case in most fields of engineering, which stress their technological (systematic) character and the scientific principles underlying their work. Yet engineering frequently involves artistic processes as well. Heuristics and intuition play a role in the design process--later to be checked and validated systematically--and aesthetic criteria are frequently applied in the form of elegance, gracefulness, economy, and related features of the product.

Curriculum, as a rank newcomer among fields of design, has not yet developed a firm image or stance on the science vs. art dimension. This is perhaps fortunate since it allows us, in conceiving of a discipline of curriculum design, to view it as both a science and an art. Curriculum design, like other fields of design, requires a delicate balance between artfulness and scientific rigor. Without art, the curricula and instructional programs produced are likely to be pedestrian--uninteresting to learners or teachers. Without science, they are likely to overlook useful instructional principles or to embody costly superstitions concerning effective methods. If either

art or science is weak, a curriculum is less likely to be effective and attractive than if art and science are well combined in the design process.

The body of this paper has had more to say in a direct way about the science than about the art of curriculum design. This is partly because we lack even a language of aesthetics for the field of instruction, and indeed for education in general, while we have at least the working beginnings of a science of instructional design based on the activities of the past dozen or more years in applying principles of psychology and related behavioral disciplines to the task of education. We speak easily, for example, of effectiveness and efficiency with respect to instructional design products, but we have difficulty in dealing with elegance as a criterion in instruction.

Difficult as it is to define, distinctions between elegant and inelegant instruction seem possible. Instruction that is playful, that represents complex relationships in simple terms, that engages learners' attention as a result of its internal structure--all of these contribute to a sense of elegance in curriculum; and all are probably related in ways yet to be understood to the more pragmatic goals of effectiveness and efficiency. Thus, while focusing in this paper on an emerging science, I have tried here and there to point out places where artistic processes and artistic criteria seem to play an important role in what I hope will be the coming shape of a science of curriculum design. The discipline of curriculum design can ill afford the parallel development of two cultures--scientific and artistic. Rather, the two must interact, with the instructional environment ultimately serving as both laboratory and studio, a place where its processes are observed and where both scientific and artistic standards are brought to bear in the interests of education.

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